Consequences of Selection for Digestibility on Feeding Activity and Excretion

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Apparent metabolisable energy corrected to zero nitrogen retention (AMEn) was used to select chickens for high (D+) or low (D-) capacity to digest a wheat diet. Consequences of this selection on digestive tract (gizzard and small intestine), feeding behaviour (number of pecks to the feed, number and length of meals and time between meals) and excretion (dry excreta weight, nitrogen and phosphorus excretion, and excreta water content) has been measured on birds from the 7th generation of selection, fed *ad lib.* or by meals either with wheat or corn diets. D- birds pecked and consumed feed 16-19% more and had 29% smaller gizzards than D+ birds. Differences between lines for digestibility, nitrogen, and phosphorus excretion were stronger for wheat diet given *ad lib.*, smaller with other treatments. For example, phosphorus excretion was 52% higher in D- when fed *ad lib.* with wheat, 16-33% for other diets. Independently from line or treatment, phenotypic correlations indicated a strong link between AMEn and raw, nitrogen, and phosphorus excretion (-0.43 to -0.99). Correlations between AMEn and feeding behaviour or anatomy were dependent on line and/or treatment. AMEn was correlated with feed consumption and number of pecks to feed only in D- birds (-0.45 to -0.76). AMEn was correlated with gizzard weight in D+ but with small intestine weight in D- birds. Therefore, our results indicated that selection on AMEn affected environmental impact, feeding behaviour and anatomy of birds, but that mechanisms involved in both lines are probably different.

Keywords: digestibility, selection, behaviour, environment, broiler, gizzard, wheat

Introduction

Improving the capacity of animal to digest its feed is an alternative way to improve feed efficiency in chickens and to reduce its environmental impact by reducing excretion. This has been proven to be successful by a divergent selection experiment for a high (D+) or low (D-) capacity to digest a wheat-based diet, assessed by AMEn (apparent metabolisable energy corrected to zero nitrogen retention, Mignon-Grasteau *et al.*, 2004). Garcia *et al.* (2007) showed that gizzard and intestine were important elements of the difference between both lines, and that feed consumption was much higher in D- birds. Rougière *et al.* (2010) found that transit was different in both lines, but nothing is known about the link between digestibility and feeding activity. Moreover, Carré *et al.* (2008) and Mignon-Grasteau *et al.* (2010) showed that the differences between lines strongly depend on diet given to animals, with higher differences obtained on lower digestibility diets. The aim of this study was then to study relationships between digestibility, feeding behaviour, and anatomy of the digestive tract and its consequences on excretion. Correlations were estimated separately for both lines and on different diets, to check whether mechanisms affected by the selection and sensitivity to the diet were the same in D+ and D- lines.

Materials and methods

ANIMALS

We used a total of 144 male and female birds issued from the 7th generation of selection of D+ and D- lines. Animals were reared in collective cages of 4-5 chicks during 3 d and thereafter in individual cages until D24. Half of birds were fed with a wheat-based diet, the other half with a corn-based diet. These diets have been formulated to contain the same amount of available nutrients. For both diets, half of animals had *ad lib.* access to feed (AL_W for wheat, AL_C for corn), the other half received two meals of 1 hour per day (M_W for wheat, M_C for corn).

MEASUREMENTS

Animals were weighed at 17, 22, and 24 d, their feed consumption measured between D17 and D24 allowing the calculation of feed conversion ratio (FCR). Between D20 and D22, a total collection of individual excreta was made, and excreta weight relative to consumption (EW) and water content of excreta (EWC) calculated AMEn and coefficient of digestive use of proteins (CDUP) were measured thanks to near infrared spectroscopy (NIRS) analysis of dried excreta (Bastianelli *et al*., 2010). Phosphorus content of dried excreta was also measured (PE). At D24, animals were slaughtered and the relative weight of their gizzard (GW) and small intestine (IW) were recorded. The ratio of GW to IW (GIR) was calculated as an indicator of digestion capacity. Animals were video-recorded during the light period (8 h/d), one day per week and per bird in weeks 2 and 3. The number of pecks (NP) to the feed, the number and length of meals (NM, LM), and the time between meals (TBM) were recorded. NP were then summed by 5-min periods, and meals were defined as consecutive 5-min periods during which animals were pecking to the feed, two meals being separated by at least one 5-min period with no peck to the feed.

STATISTICAL ANALYSIS

Analysis of variance was performed on all traits including fixed effects of line, sex, cell, and age of animal (SAS, 1999). For feeding behaviour traits, an animal effect was also included in the model to take into account the repetition of observations for the same animal. Phenotypic correlations between all traits were calculated separately by line and treatment (SAS, 1999).

Results and discussion

LINE AND TREATMENT EFFECTS ON TRAITS (cf. *Table 1*)

Line by treatment interaction was significant for AMEn, EW, PE, and IW. For these traits, D+ birds had 15 to 52% higher values than D- birds (depending on trait considered), whereas no significant difference was present for M_C (2 to 16%). In D+ line, birds were more efficient,

produced less excreta and had a lighter small intestine. In AL_W treatment, birds were faced to a diet difficult to digest, but could increase their consumption. At the opposite, in M_C treatment, diet was easy to digest but FC limited by the time given to birds for eating.
Between treatments, NP was 19% higher in D- than in D+, reflecting the difference of feed consumption between lines (+16% in D-). However, LM, NM, and TBM were not affected by line. Within treatments, no difference in NP was observed between lines, whereas FC differed on *ad lib.* animals. This could suggest that when feed is severely restricted, feed pecking is followed by ingestion, but at the opposite, when feed is not restricted, D+ performed more exploratory pecks than D- birds. Finally, a strong difference was also present for GW and GIR, D+ birds showing heavier gizzards and higher GIR than D- birds (29-47%), as already found in Garcia *et al*. (2007) and Rougière *et al.* (2009). Finally, a smaller but significant (P=0.05) difference was observed for CDUP and EWC, both higher in D+ than in D- line.

Table 1 Significance of the effects of line (L), Treatment (T) and their interaction (LT), and least square means of traits by line and treatment.

Trait	Significance of effects			D+				D-				MSE
	L	T	LT	AL_W	AL_C	M_W	M_C	AL_W	AL_C	M_W	M_C	
NP	***	***	NS	2570^{ab}	2090^{bc}	2808^{ab}	1644^{c}	3293^{a}	2215^{bc}	3311^{a}	2053^{bc}	957
LM (min)	NS	***	NS	55.0^{ab}	53.0^{ab}	26.0^{c}	19.5^{c}	61.0^{a}	45.0^{b}	29.5^{c}	27.5^{c}	16.5
NM	NS	***	NS	20.0^{a}	20.8^{a}	3.8^{b}	4.4^{b}	20.2^{a}	21.6^{a}	4.0^{b}	3.7^{b}	2.8
TBM (min)	NS	***	NS	68.0^{a}	66.0^{a}	11.5^{b}	12.0^{b}	64.0^{a}	71.0^{a}	8.5^{b}	10.0^{b}	18.5
FC (g)	***	***	NS	84.5^{bd}	82.9^{bd}	73.9^{bd}	70.8^{cd}	100.1^{a}	96.6^{a}	86.5^{ab}	79.3^{bc}	83.7
AMEn(kcal/kg)	***	***	***	3048^{bc}	3024^{bc}	3160^{ab}	3074^{ab}	2650^{d}	2887^{c}	2892^{c}	3017^{abc}	164
CDUP (%)	***	***	NS	80.0^{cd}	82.9^{ac}	83.7^{bc}	84.7^{ab}	73.6^{e}	78.1^{d}	79.2^{ad}	82.5^{c}	3.6
EW	***	***	***	33.1^{bc}	29.8^{c}	29.1^{c}	28.4^{d}	45.2^{a}	34.0^{bc}	37.5^{b}	30.2^{cd}	4.9
EWC (%)	***	NS	NS	76.2^{ab}	75.8^{ab}	76.6^{a}	73.6^{ab}	68.1^{b}	74.5^{ab}	71.1^{ab}	73.0^{ab}	7.3
PE (g)	***	***	***	3.24^{b}	3.33^{b}	2.34^{c}	2.52^{bc}	4.94^{a}	4.36^{a}	3.11^{bc}	2.93^{bc}	0.78
GW (%)	***	***	NS	2.40^{ab}	2.39^{ab}	2.48^{ab}	2.92^{a}	1.56^{c}	1.92^{bc}	2.01^{bc}	2.38^{ab}	0.52
IW (%)	***	***	***	3.34^{cd}	2.97^{d}	3.28^{c}	3.60^{ac}	4.06^{a}	3.60^{ac}	4.01^{ab}	3.54^{bc}	0.40
GIR	***	***	NS	0.73^{ab}	0.81^{a}	0.76^{a}	0.81^{a}	0.39^{d}	0.55^{bcd}	0.51^{cd}	0.68^{ac}	0.16

***: $P<0.001$, NS: non significant; AL_W, AL_C: wheat or corn diet, *ad lib.;* M_W, M_C: wheat or corn diet, meals (2/ day)

CORRELATIONS BETWEEN AMEn AND EXCRETION

AMEn and EW were strongly correlated whatever the treatment or the line (-0.71 to -0.99), indicating that the most efficient animals produced less raw excreta. These values are consistent with the genetic correlation between AMEn and EW of 0.99 obtained by Mignon-Grasteau *et al.* (2004) in the same lines fed with wheat. Similarly, nitrogen and phosphorus excretion were linked to AMEn, but correlations varied a lot among lines and treatments. Correlations were high and very homogeneous between AMEn and CDUP in D+ birds (between 0.80 and 0.89) and lower and more heterogeneous in D- birds (between 0.63 and 0.97). Thus, animals with a higher AMEn digested better proteins and excreted less nitrogen. In D+ line, phosphorus excretion was correlated with AMEn for *ad lib.* treatments (ρ=-0.47 to -0.68), but not for meals treatments (ρ=-0.06 to -0.33, $P>0.05$). In D- line, this correlation was significant in AL_W, AL_C, and M_W treatments (ρ=-0.43 to -0.71), but not for M_C (ρ=-0.24, $P>0.05$). Animals with better digestibility logically excreted less phosphorus, but only when animals were fed *ad lib.*, mechanisms linking both traits being probably different when animals were fed-restricted. Finally, the relationship between AMEn and EWC was opposite in D+ and D- lines. Correlation was significant only for AL_W in D+ line (ρ=0.54), only in AL_C, M_W, and M_C in D- line (ρ=0.35 to 0.47), but the sign of the correlation was always the same, indicating wetter excreta in good digesters.

CORRELATIONS BETWEEN AMEn AND FEEDING ACTIVITY

In D+ birds, there was no relationship between AMEn and feed consumption or feeding activity, correlations ranging between -0.19 and 0.25 with FC, between -0.32 and 0.42 with NP, NM, TBM, and LM (P>0.05). Efficiency of D+ birds is therefore not linked to their ability to ingest more feed during the day or to eat quickly when they are fed-restricted. At the opposite, in D- birds with AL_W treatment AMEn was correled with NP (ρ=-0.45) and FC (ρ=-0.76). The bad digesters probably increase their feed consumption in order to compensate for their poor ability to digest feed. This relation was not present with corn. Corn is easy to digest and D- birds perform well on this diet. When animals were fed-restricted, the capacity to make fewer but longer meals in the meanwhile could compensate a low AMEn when diet is not too difficult to digest, i.e. for M_C treatment (ρ(AMEn, LM)=0.57; ρ(AMEn, NM)=-0.38). When a wheat diet difficult to digest was used (M_W), there was no relationship between AMEn, FC, and feeding activity (ρ=-0.05 to 0.28), probably indicating that they were not able to compensate their lower digestibility by an increased consumption of food when access to feed is limited in time.

CORRELATIONS BETWEEN AMEn AND ANATOMY OF DIGESTIVE TRACT

When animals were fed *ad lib.*, AMEn was correlated with gizzard weight in D+ birds and with small intestine weight in D- birds. The correlation was negative in AL_W and AL_C for D- birds (ρ(AMEn, IW)= -0.35 and -0.75, resp.), suggesting that, whatever the size of the gizzard, animals with the poorest digestion capacity had the longer intestine. It can be hypothesized that increasing the surface of nutrient absorption allows them to compensate for their poor digestibility. In D+ birds, animals with the heaviest gizzards had a better digestibility for wheat (ρ=0.45), but a poorer digestibility of corn (ρ=-0.54). This negative correlation between AMEn and GW is also present with the M_C treatment (ρ=-0.80), but in that case, AMEn and IW were also strongly and negatively correlated (ρ=-0.87). In D- birds, contrarily to what was observed for AL_C, AMEn was positively correlated with GW (ρ=0.75), but not with IW (ρ=-0.34). Finally, on M_W treatment, no correlation was found between AMEn and anatomy of the digestive tract (ρ=-0.09 to 0.14).

Conclusion

Our results showed that selection for AMEn decrease environmental impact of chicken production by reducing bird manure production as well as nitrogen and phosphorus excretion. It has also modified feeding behaviour and anatomy of the digestive tract. Moreover, the sensitivity to the diet and to feed restriction has also been modified as genotype by diet interactions were present for excretion and anatomy of digestive tract. These results suggest that mechanisms that have been modified by the selection differ in D+ and D- lines, and that these mechanisms are sensitive to the diet.

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